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Nanosatellites: The Tool for Earth Observation and Near Earth Environment Monitoring

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1. Introduction

Large satellites continue to be affordable only to big national projects or extremely wealthy organizations. As such, emerging countries and small organizations are adopting smaller spacecrafts as means to their space exploration endeavours by forcing the miniaturization age to the space industry. In this chapter we evaluate the possibilities of using nanosatellites with the aim of achieving the best return of scientific output.

Adopted almost exclusively by small organization with limited budgets (universities, private firms or research institutes), nanosatellites have as their main requirement the maintaining off the overall costs at minimum. Unlike the traditional space missions, the nanosatellites use commercial off the shelf components - COTS - in order to decrease costs and fast track the design. This was identified as a liability since the space industry generally requires extensive qualification campaigns for flight hardware. But this is also a strong point since satellites can be designed, built, launched and operated in a fraction of the time required for conventional spacecrafts and at costs orders of magnitude lower.

The small scale counter parts of the traditional space missions represent the tool for Earth observation and near Earth space monitoring in the new age of space explorations. Almost 10 years ago the beginning of this new age became clear with the introduction of the CubeSat standard.

Generally, the nanosatellite term designates satellites in the 1 – 10 kg mass range. However, the most representative for this class is the CubeSat which restricts developers to a volume of approximately 10 x 10 x 10 cm³ (Cal Poly SLO, 2009). Recently there have been developments of sub-nano (pico class) spacecrafts weighing several hundred grams, or even smaller to femtosats – the so called satellites on a chip. However, their characteristics are yet unknown as they are only in the early design phase at present.

Although there are many representative of the nano class, the standardization of the launcher interface and the deployer (P-POD) has helped the CubeSat to receive general acceptance as the de facto standard. Previous experience with small satellites existed before the CubeSats, but their introduction marks the moment when a critical mass of developers begun working on similar designs using similar components. The simultaneous introduction of the P-POD

also brought a standardized interface to various rockets. As such it became easier for the developers to address launching organizations for a group of small satellites.

As nanosatellite developers, we propose the adoption of these types of spacecrafts to support Earth observation, space environment monitoring and space qualification efforts at minimal costs.

1.1 Typical characteristics of nanosatellites

The definition of the satellite classes is not very rigid. Contrary to general perception, the exterior dimensions are not defining the nanosatellite. Typically, when speaking of a nano class spacecraft we refer to a sub 10 kg satellite. Consequently, the mass restriction is also a size restriction limiting the exterior dimensions to tens of centimetres. The only standard that imposes restrictions on dimensions is the CubeSat – a cube with a 100 mm edge length permitting small protuberances up to 6.5 mm on each side. The standard also limits the mass of the spacecraft at 1.33 kg – recently upgraded from 1 kg. A deviation from the initial standard allows the use of the space equivalent for two or three CubeSats (or even halves) for a single satellite extending the maximum length at more than 200/300 mm but maintaining the other two dimensions unchanged. These variations from the standard are named double or triple CubeSats to differentiate them from the single cube models. It is worth mentioning that even if the standard permits it, there have been no double CubeSats launched but only single or triple units.

The main characteristic of the nanosatellite are given by their size, which is in the order of tens of centimetres. All the other subsystems need to be scaled down to accommodate the design requirements. There are two approaches in designing a spacecraft of the nano class: either start from the payload and scale the satellite to that payload (traditional method very unusual for small satellites) or scale the payload to the overall dimensions and try to accommodate the other subsystems. The later is the new method that involves setting a design for the payload and revisiting it if after adding the rest of the subsystems the overall restrictions are not met. This might require going into many iterations for the design of the payload and the subsystems.

1.1.1 Electrical power

The accessible power on board a satellite depends on the total surface area available for solar cells. Using the formula in equation (1) we can compute the maximum power one square side can generate. The first term is the solar constant (the power from the Sun light available on Earth's orbit on a dm²), the second term is the surface area exposed to the Sun light, while the third term is the conversion coefficient between light and electricity.

$$P_{side}^{max}[W] = 13.68 \left[\frac{W}{dm^2}\right] \cdot S_{side}[dm^2] \cdot \frac{C[\%]}{100} \tag{1}$$

For the 10 kg satellite a gross estimation of the size is a cube with the edge length of 200 mm. If we presume that no deployable solar panels are used, the total surface available for photovoltaic cells is 4 dm² for each of the 6 sides. Considering the solar constant at 13.68 W/dm², and the average conversion coefficient 25%, the total power available when not in eclipse must be lower than 18 W. This value does not take into account Earth's albedo.

The single unit CubeSat is situated at the lower limit of the nano scale according to the definition, so the available surface and electric power is even lower. Repeating the previous calculations for a 10 cm cube gives a value of 4.5 W for the maximum instantaneous power available without deployable solar panels. Just like with the previous estimate we assume no variation of the conversion coefficient associated with the increase of the temperature on the photovoltaic cells and we presumed the satellite in an orientation corresponding to the maximum surface area directly exposed to the Sun. Orbit averages for the power will be significantly lower than the computed values if we take into account the time the satellite spends on eclipse – typically 30% of the orbit period. Deployable solar panels have been included in launched CubeSats, especially for triple units, but for single unit as well (Nakaya et al., 2003; Genbrugge et al., 2009).

1.1.2 Orbit

Due the average power being on the order of watts or tens of watts the nanosatellites are constrained on accessible orbits as well. The limited power available for the transceivers restricts the range between the ground station and the spacecraft. Consequently, nanosatellites are launched on low Earth orbits (LEO). The typical orbit is circular at almost 90° inclination and its altitude is near 700 km. The second, less encountered orbit class is also circular but at 300 – 350 km and its inclination much lower – Genesat-1 and satellites launched from the ISS or the Shuttle. These orbits are at the lower limit of the trapped radiation belts and although the particle fluxes are higher than at sea level they are inferior to those on higher altitude orbits. This is the main reason that COTS components are feasible to be used on board nanosatellites.

9 CubeSat class satellites will be launched on a non characteristic orbit on board the VEGA maiden flight. The orbit has changed several times but the current values for the perigee and the apogee are 300 km and 1450 km with the inclination at 69.5°. The higher altitude of the apogee takes the satellites inside the proton belt. The satellites launched on this mission would further evaluate the possibility of using COTS at high radiation fluxes.

The orbit of the nanosatellite also impacts the communication between the ground station and the spacecraft. For the orbits we previously mentioned a full period is approximately 90 minutes and each day there are between 3 and 5 windows of communications when the satellite is in range of the spacecraft and 3-10 minutes on each interval. These values are averages for a location at 45° latitude. There is daily re-visitation for satellites on LEO and this fits well into the objective of using nanosatellites for Earth observation applications.

1.2 Currently available technologies

Being in development for over a decade, different technologies have been adopted by the nanosatellite designers and advances have been made for increasing the capability of these spacecrafts. We are now at a time when the efforts are starting to show results and in-mission demonstrations of these technologies are beginning.

1.2.1 Processing power

A second important restriction imposed by the energy available on board is the processing power that can be feasibly accommodated on small satellites. Hence the on board computers

typically found on nanosatellites launched in the past decade are microcontrollers functioning at frequencies of several MHz. The reason is not the lack of advanced processors that could be integrated, but the need to limit the functioning periods for them as they drain the batteries rapidly. The proposed solution is to use a mixed approach: low power microcontrollers for general functions and high power processor for demanding tasks like attitude determination and control systems (AOCS) or data processing in payload units. This method has already been applied by the integration of units functioning at hundreds of MHz on board nanosatellites already launched or being scheduled for launch.

Launched in 2008, the Japanese nanosatellite Cute-1.7 + APD II used the main boards of two commercial off the shelf (COTS) personal device assistant (PDA) running at 400 MHz as the main components of the on board computer and data handling system (OBDH) (Ashida et al., 2008). Scheduled for launch on the VEGA maiden flight, the Goliat CubeSat integrates a dual core 600 MHz digital signal processor (DSP) for on board image compression (Balan et al., 2008).
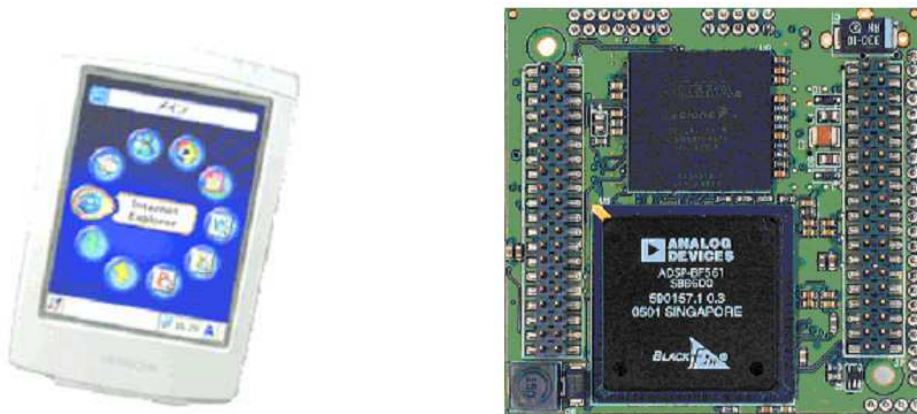

Fig. 1. Hitachi NPD-20JWL PDA on board Cute 1.7 + APDII (left) and the DSP board on board Goliat (right).

The trend of adapting commercial portable devices like PDAs and smartphones for use on board nanosatellites fits the general guidelines of low cost design through the use of COTS subsystems. Additionally, mass produced mobile devices are benefiting from extensive research in miniaturization and reduction of power consumption, levels that can't be achieved with the limited budgets of a small satellite research project. Therefore the orientation of nanosatellites developers toward using smartphone processor boards as part of theirs satellite's OBDH system is natural.

The most popular mobile platforms of the moment, iPhone and Android, have proven flight experience at the edge of the atmosphere, on board weather balloons at altitudes higher than 30 km. Taking the idea a step further, a team of researchers in UK plans on building and launching a triple unit CubeSat that will fly a complete smartphone (Surrey Satellite Technology Ltd, 2011). The smartphone will be the payload and the demonstration of its orbit functioning is intended. Part of the test also implies switching off the main microcontroller of the satellite and passing all the OBDH functions to the smartphone.

Besides costs and power optimization there are other benefits of adapting the processors of mobile devices to satellites: better development tools for software with better version

control, usability of the same code among several devices facilitating the upgrade of the hardware with minimal software changes, a single low voltage power supply (typically 3.3 V) and a single data interface, numerous integrated peripherals (magnetometers, accelerometers, gyroscopes, temperature sensors). These benefits also come with the loss of some of the customization as there is little possibility to intervene on the hardware (sensor calibration, removing unnecessary modules) and some parts of the software. The number of additional interfaces is also limited and typically a single serial connection exists: Bluetooth. Additionally, USB host mode connection is being proposed as standard for smartphones running the next release of Android OS (version 3.1).

As part of our research, we propose the use of the on board data connections – mainly Wi-Fi, but GPRS or 3G also – as communication platforms for nanosatellites flying in close or dispersed orbital formations. If Wi-Fi devices allow ad-hoc networking, the use of the mobile phone data connections will necessitate the existence of a cell node managing the network.

1.2.2 Attitude and orbit control systems

Most advanced applications require precise determination of the orbit and the attitude of the satellite. Others also need capabilities to change the orientation and some even the position of the satellite. This is the technology field where most nanosatellite research is focused. Miniaturized attitude determination sensors existed at the time nanosatellites started being launched and various sensors were rapidly integrated: Sun sensors, magnetometers, Earth horizon sensors, star trackers.

Beside early attempts at using permanent magnets or magneto-torquers to stabilize the satellite or change its orientation, recent developments have been made at integrating reaction/momentum/inertial wheels on board even the CubeSats – see Fig. 2 (Balan et al, 2008; Bozovic et al, 2008). The CanX-2 was developed and launch for testing some of the critical components of the AOCS system required in the formation flying demonstration mission of CanX-4 and CanX-5. As such, the triple unit CubeSat included a complex attitude determination system based on multiple sun sensors and a magnetometer. It also integrated a single reaction wheel for evaluation purposes together with a propulsion system evaluation unit. The team reported successful operation for all the AOCS subsystems evaluated (Sarda et al., 2010).
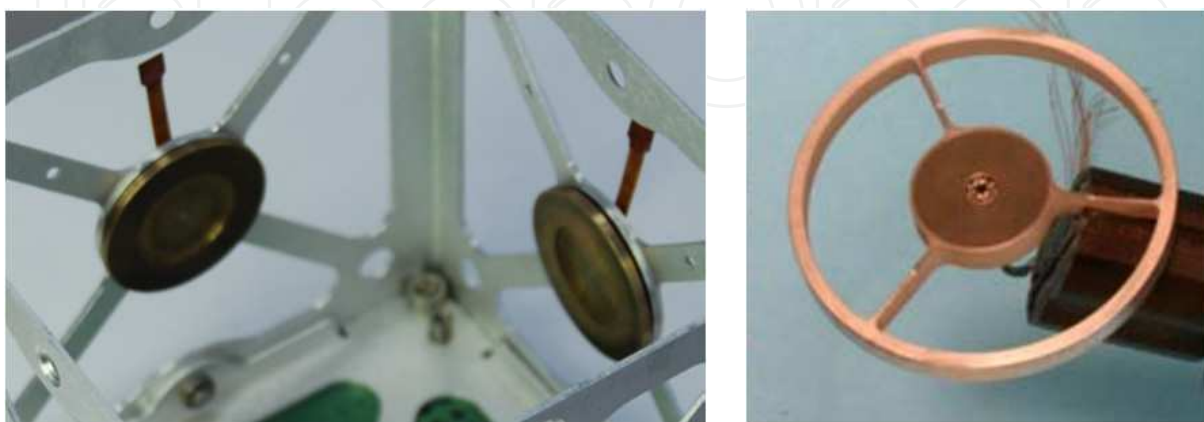

Fig. 2. Motors and reaction wheels on the mechanical structure of Goliat (left), motor and the inertial wheel assembly for the SwissCube (right).

For nanosatellites bigger than single unit CubeSats, different commercial solutions have emerged recently. One such example is the MAI-x00 series which offer complete attitude determination and control for small satellites in packages from half a CubeSat to 1 CubeSat (Maryland Aerospace Inc., 2011). Position actuator products are not as advanced for small satellite, and either cold gas or micro thrusters are considered. A different approach is the use of aerodynamic breaking in close orbital formation scenarios. For two or even more CubeSats launched from the same deployer, the initial velocities are the same. Any change in the orientation results in a change of the surface area normal to the trajectory and in a change of the aerodynamic drag. Such a solution will work only in preventing the spacecraft separation and it actuates only in the direction of the orbit. Any difference in the velocities of the two spacecrafts for the other two axes would render the method unusable (Balan et al., 2009).

After a decade of nanosatellites missions the technologies have evolved enabling the exploitation of the new class of spacecrafts for more complex applications. As the subsystems available have evolved, sufficient flight data has been gathered for essential components and their reliability is guaranteed.

2. Earth observation and near Earth environment monitoring

The objectives of small spacecrafts were initially only educational while science and Earth observation were just viewed as secondary goals. However the nanosatellites' missions have quickly begun to evolve to more complex science with increased demand for reliability. From the industry perspective, nanosatellites now represent an easy access to space for simple instruments or for test bed applications. Among the instruments best suited are the sensors for monitoring the radiation environment on LEO, the magnetic field and some of the upper atmosphere phenomena. The inclusion of digital cameras on board nanosatellites did not have Earth observation objectives at first. Initially the imaging experiments were included for their public outreach potential.

The Earth observation potential of nanosatellites is still disregarded since optic instruments are considered too large for integration on nanosatellites. However as the exploitation potential of the new class of spacecrafts was revealed, the idea of Earth observation even on CubeSats starts to gain more general acceptance with every new launch. A camera having one of the highest focal lengths mounted on a CubeSat is part of the Goliat mission. Its integration proved very difficult as the optical lens and sensor assembly occupy almost half of the interior of the spacecraft.

One of the advantages of LEO is the proximity to the surface and to the upper atmosphere. Earth Observation doesn't target only the monitoring of the land or water masses, but also the monitoring of phenomena in the atmosphere. Small focal distance cameras are ideal at imaging the movement of large cloud formations (like with tropical storms or large scale meteorological manifestations). Also, we mentioned earlier the re-visitation interval of approximately 12 hours which is important for events with high dynamicity. These time intervals can be further decreased if several nanosatellites (a constellation) are deployed on the same orbit in successive launches. The satellites cover the same area at time intervals several hours apart with the actual timing depending on the number of spacecrafts launched.

A special application for low resolution image acquisition that could be implemented on nanosatellites involves multi-spectral imaging on board satellites flying in a close orbital formation. An identically built satellite is to be repeated and the optical systems will be the same among all the members of the orbital formation. Unlike the large spacecrafts, the imaging sensors on each satellite can be single-spectral, and the wavelength for the maximum sensitivity is the one that differs. For redundancy multiple spacecrafts will monitor each spectral band and the image acquisition will be commanded to all satellites. Multi-band images can be reconstructed either on ground or on the network on orbit. However, for each band a single image will be sent to the ground station, resulted from the fusion of all the images taken by satellites with the same spectral band sensitivity – see Fig. 3 (Balan et al., 2009).
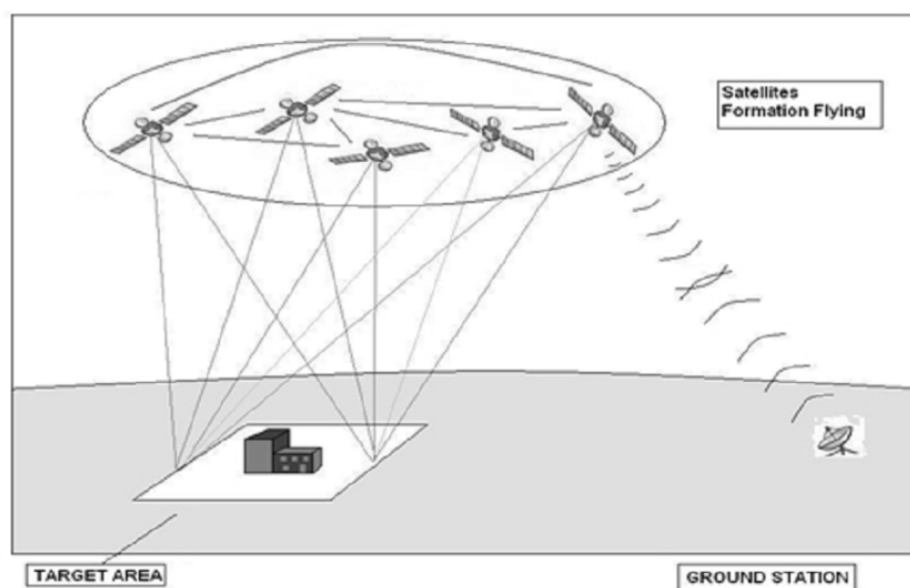
Fig. 3. Formation flying scenario with distributed sensors, in flight data processing and single data stream communications.

One of the key application of nanosatellites is as support in disaster management efforts. In these situations low re-visitation periods are required to monitor major floods, fires or other large scale natural disasters. For these types of conditions, rapid information delivery is more important than resolution as there is an immediate need to roughly identify the areas already affected and the ones most exposed to danger. Nanosatellites can therefore be used in conjunction with large spacecrafts to identify precisely the locations where higher resolution images are required and request the specific areas to be monitored.

Several approaches have been proposed to address the problem of the size of the optical systems. Among them, worth mentioning are the use of complex deployable lens mounts and the use of multiple sensors. A nanosatellite that successfully demonstrated deployable optics is the 8 kg, 19 cm x 19 cm x 30 cm PRISM nanosatellite developed by the Intelligent Space Systems Laboratory (ISSL) of University of Tokyo (Komatsu & Nakasuka, 2009).

The advantage of nanosatellites is their reduced costs. If multiple identical such spacecraft are to be built, the costs are decreased even more. As such, it is natural to consider multiple satellites scenarios in which the imaging of the same area, or adjacent sectors

would result in a representation of higher resolution. The solution is not complete if the image processing is set to be conducted on ground as all the raw data from the sensors must be forwarded to the ground station. This situation is not feasible for nanosatellites as there is a limited data rate caused by the limited power. Therefore the use of on board processing for all the data acquired by the distributed sensors is a necessity. As resources are limited on nanosatellites, the ideal method for implementing complex data processing is by using the hardware on each of the spacecrafts and dividing tasks among processors based on their availability, like in grid computing. This complex image processing method was not yet implemented on launched satellites. The main issue is with scaling down the data fusion algorithms so they can be implemented on the limited hardware resource on board nanosatellites.

Precise Earth observation requires the use of key technologies identified in the previous section. The most obvious among the requirements is the need to determine the position and orientation of the satellite with the accuracy needed by the application – approximately 10% of the ground target size. The same resolution is required when controlling the orientation actuators. Once the image has been stored on board, the data must be sent to the ground station. The reported data rate in nanosatellite to ground station communications has increased in the last couple of years with the use of S-band transceivers and the utilization of the experience acquired during the operations of the first spacecrafts. Given the limited emission power, the data throughput can be increased if directive antennas shall be developed for use on the nanosatellites. Furthermore, even if the data rate is not increased, the amount of data transferred to the ground station can be increased by optimizing the radio communications windows. At present, with mid-latitude ground stations, the communications windows are less than 10% of the orbital period. A second ground station could increase the percentage, but either the separation among ground stations must be of hundreds to thousands kilometres, or each ground station must target a different satellite and different data streams are to be transferred. Single ground stations that can have greater communication windows must be situated in the Polar Regions if the polar orbits remain the custom for nanosatellites. An alternative is represented by the ground station networks currently being proposed – GENSO – but these are tailored for educational purposes and need to be adapted to the different needs of the commercial applications.

It is expected that the time from design to delivery for a nanosatellite missions to further decrease, and the mission costs to continue to go down together with it, due to the rapidly increase in the nanosatellites subsystems and components market.

3. Multiple satellites mission for Space Situational Awareness (SSA)

The multi satellite missions are best suited for small spacecrafts due to the small costs and rapid production associated with them. We present distributed measurements as a new way to better and faster understand complex phenomena by using simultaneous data gathering in the target environment. A group of nanosatellites (constellations or formations) is the most cost-effective way to implement this approach in space. Furthermore, distributed data collection can be correlated with distributed processing to enable single data stream transmissions between the spacecrafts in orbit and the ground station as opposed to the multiple streams associated with independent multiple satellites. This solution better

addresses the issues of limited data rate in small satellites communications caused by the low available power and not using directive antennas. Unlike with imaging applications, the amount of data from multiple instruments in a close orbital formation can easily be transmitted from a single satellite even if measurements from each sensor are included. Raw signals from every event will however have the same impact as images on the size of data to be transmitted, but in the case of unusual results, the actual values recorded can be sent in multiple transmissions without impacting the stream of on board processed data.

The potential of small satellites, nanosatellites and CubeSats especially, to contribute valuable data necessary to the modelling and the prediction of the space environment in the context of the SSA has recently begun being recognized and the need to aggregate all the data from recent small satellites launches is identified (Holm et al, 2009). Extrapolating on this trend we consider there is a further need for a unified data collection structure with multiple points of acquisition and multiple similar – identical or complementary – sets of sensors. Nanosatellites are the perfect propositions for demonstrating the benefits of this type of missions due to the reduced mission costs and their rapid development.

One of the main directions in the field of near Earth space monitoring is the research and development of spacecrafts built for multi-satellite missions. Space weather's influence on our daily life increases constantly with the miniaturization as devices become more sensible to outside interferences. Within the context of a new maximum in the solar activity, the perturbations of space supported services are becoming more frequent so we base our mission proposition on the need to investigate this domain. Multiple spacecrafts missions, in either constellation or formation configurations, will serve as points of observations for the evolution of the complex environment of nuclear particles in conjunction with the dynamic magnetic field of the planet.

Based on the experience in developing the radiation detection experiment on board Goliat, we proposed the further investigation of the nuclear particles in LEO and the magnetic field, in order to identify correlations between local variations of the two. Observations on the dynamics of the phenomena are possible by using the distributed sensors and the short re-visitation intervals. All spacecrafts are to be identical from the hardware point of view. The minimal requirements for the radiation sensors are the need for differentiation based on particle type and the capability of measuring the energy of each event so as to obtain the representation of the radiation spectrum at each satellite. Precise magnetic field measurements require caution in separating the interferences generated by the spacecraft's own subsystems. This is why magnetometers need to be mounted as far from the satellite as possible, usually at the end of a deployable boom. Each spacecraft needs also to integrate precise attitude determination for both position and orientation of the magnetometer's axes with respect to the Earth.

Space weather monitor nanosatellites can be launched in solitary missions as demonstrators, but greater value can be added by launching several in a close orbital formation. In the first months of their mission, they will synchronize data collection between them and the data transmissions to the ground station are centralized through a single point of contact – one member of the formation. As the atmospheric drag starts affecting each satellite differently, their relative velocities change and the distances among satellites will increase. The

formation transforms into a constellation and the phenomena recorded are no longer local, but become global.

The same approach can be applied to multiple applications in the context of SSA. The mixed configuration mission can theoretically fulfil both roles: being launched as a close orbital formation and, once the fuel has run out, gradually migrating to a dispersed formation and then becoming a constellation. The simplest demonstration would require launching three identical single unit CubeSats from the same PPOD and then test the formation flying capabilities on board these three spacecrafts. Such a mission can serve as a test bed for larger nanosatellites. During the demonstration various hardware and, equally important, software can be tested to facilitate future missions.

4. Case study: Goliat, building a CubeSat for Earth observation & near Earth environment monitoring

The authors of this chapter worked at developing Romania's first CubeSat class satellite - Goliat. Among its goals an important part is the demonstration of Earth observation and near Earth environment monitoring capabilities on board nanosatellites.

4.1 Goliat platform subsystems

Goliat is a single unit CubeSat developed by a Romanian consortium led by the Romanian Space Agency. The project was directed toward students at two universities in Bucharest that were tasked at designing and building the satellite in order to have them educated in the work practices of the space industry. The project involved not only building the satellite, but also setting up a ground station infrastructure at two locations near two major cities in Romania: Bucharest and Cluj-Napoca.
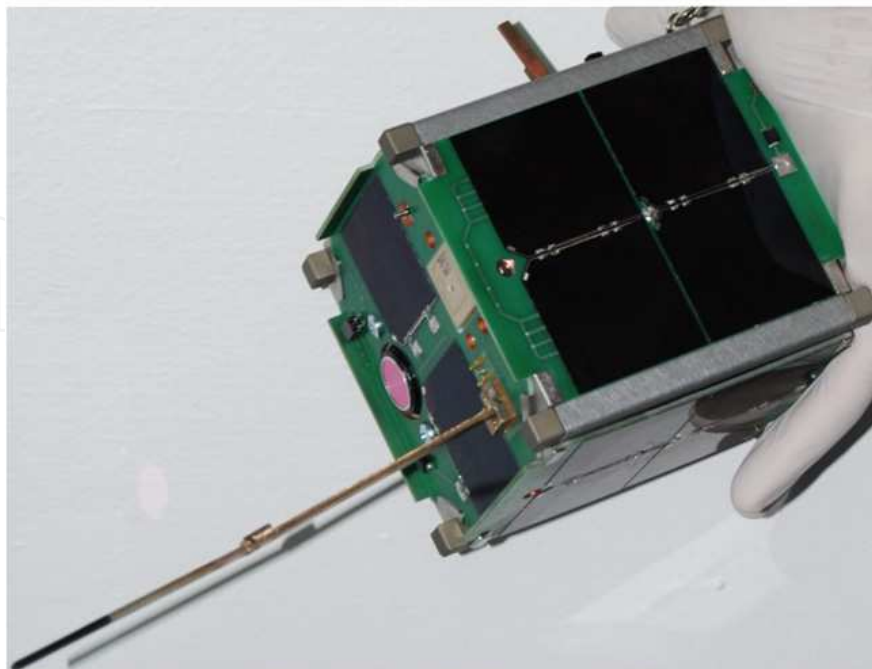

Fig. 4. Goliat Flight Model.

The satellite was selected to be launched on Vega's inaugural flight on an elliptical orbit having the perigee at 300 km and the apogee at 1450 km. The satellite's life on this orbit is between 1 and 3 years due to rapid altitude decay caused by atmospheric drag.

4.1.1 Mechanical structure

Goliat was built in accordance with the CubeSat specification as a single unit satellite. The skeletonized version of Pumpkin's mechanical structure is the basis of Goliat's design. The +Z side of the satellite was full metal and not skeletonized as optics mounting and several other components required a harder fixture. The structure is made out of aluminium alloys with the rails hard anodized.

4.1.2 OBDH

Two MSP430F1612 microcontrollers are the backbone of the satellite. One of the onboard computer (OBC) units was acquired from Pumpkin, while the other one was a custom solution built on an internal design. The two processors are running at 7.2 MHz and communicate with each other via a serial peripheral interface (SPI). The OBC board also includes a SD card interfaced on SPI as well. Other subsystems are also communicating using the SPI link: the camera processor board and the control unit of the UHF radio. Additionally each microcontroller connects on a serial interface to various components: camera processor board, 2.4 GHz transceiver, magnetometers, GPS. Data from two experiments (radiation measurement and micro-meteoroid impact instrument) and from the housekeeping sensors is collected at the microcontrollers on the built-in ADC channels. An independent microcontroller unit was implemented on the electronic power supply (EPS) board to manage this subsystem.

4.1.3 Radio communications

Goliat has two data links for radio communications. The primary data link unit uses a 1 W commercial transceiver operating in the 2.4 GHz band. This unit is controlled and it is directly interfaced to one of the MSP430 microprocessors. It is scheduled to operate only when in range of the ground station and its main purpose is to transmit data from the experiments and to receive commands from the operators in the control room.

The secondary transceiver is a beacon operating in the 70 cm radio amateur UHF band. It is built from a portable radio-amateur transceiver and a custom built AFSK modem controlled by a third MSP430F1612 microcontroller. This radio module is meant only at transmitting but receiving capabilities have been added to act as back-up for the main radio unit. The data transmission on this link will be continuous on the entire orbit and both Morse code and AFSK packets with housekeeping data will be transmitted. This unit is controlled by a different OBC than the 2.4 GHz transceiver so full redundancy is available on the spacecraft.

4.1.4 Electronic power supply

The EPS subsystem features the power generation, energy storage and voltage conditioning functions of the satellite. The first component of the subsystem is made up by the solar

panels. 18 photovoltaic cells measuring 41 mm x 42.2 mm and having an efficiency of approximately 25% are distributed on the 6 sides of the satellite. Three sides contain 4 cells each while three sides contain only two cells each. The estimated average power from the solar panels is a little over 2 W. The cells are grouped so the voltage reaching the main EPS board is 4 V.

Due to the noise sensitive nature of one of the on board experiments, the main requirement of the EPS design was that no switching power supply should be present on the satellite's supply lines. This imposes the use of LDO regulators which are highly ineffective. More so, the need of a 5 V supply line, coupled with the less than 5 V output voltage of the solar panels, requires the use of a battery pack with the nominal voltage above 5 V. Li-Ion batteries were selected due to having the highest energy density per mass. The ping-pong architecture of the EPS uses two Li-Ion battery packs with their nominal voltage at 7.2 V. A battery pack always supplies the satellite, while the other is charging from a step-up converter that has the voltage from the solar panels as its input.

4.1.5 ADCS

For the determination of Goliat's position there are two independent methods. First uses a commercial GPS receiver while the second one involves sending the orbital parameters as a *.tle file (two line elements) and then calculate the position using an orbit propagator implemented on one of the microcontrollers. For orientation the satellite uses a triple axis magnetometer and an IGRF implementation on the same microcontroller to compare the data for the actual position and determine the orientation of the satellite with respect to the Earth.

Goliat is meant to demonstrate a simple reaction wheel system for changing the orientation of CubeSats. Due to the mission constraints only two wheels were able to be included in the satellite design. The attitude control system is made of two high precision reaction wheels mounted on top of two micro-motors and the assemblies are attached to the aluminium structure in the centre of two perpendicular sides of the satellite.

4.2 Payload

The payload of Goliat consists of three independent experiments for near Earth environment monitoring and Earth observation.

The first of them is named SAMIS and it is a micro-meteoroid detection instrument that uses a thin film piezo-element to measure the energy of the impact between the satellite and the micrometer sized particles on LEO. The measurement of the flux of particles encountered by the satellite will take place continuously after the commissioning of the spacecraft.

Dose-N is the second on board experiment and it targets the measurement of the total ionizing dose on Goliat's orbit. The experiment's added value increases with the new Vega orbit since the satellite's trajectory is no longer circular and a range of altitudes in the radiation environment is to be mapped. If the 700 km altitude orbit was at the lower limit at the trapped proton belt, the elliptical orbit enters the region and exposes the satellite's

components to higher radiation fluxes. The radiation detection instrument uses a scintillating material that generates visible radiation when interacting with nuclear particles. The light is detected by a photodiode that has its maximum sensitivity at the same wave length as the photons emitted by the scintillators (430 nm). The signal from the photodiode is integrated and the amplitude of the output signal measured by the microcontrollers as the total energy deposited in the integration time frame. Measurements will be taken at equally distanced positions along the trajectory of the spacecraft and dose measurements will be correlated with resets and other errors in the functioning of the satellite.
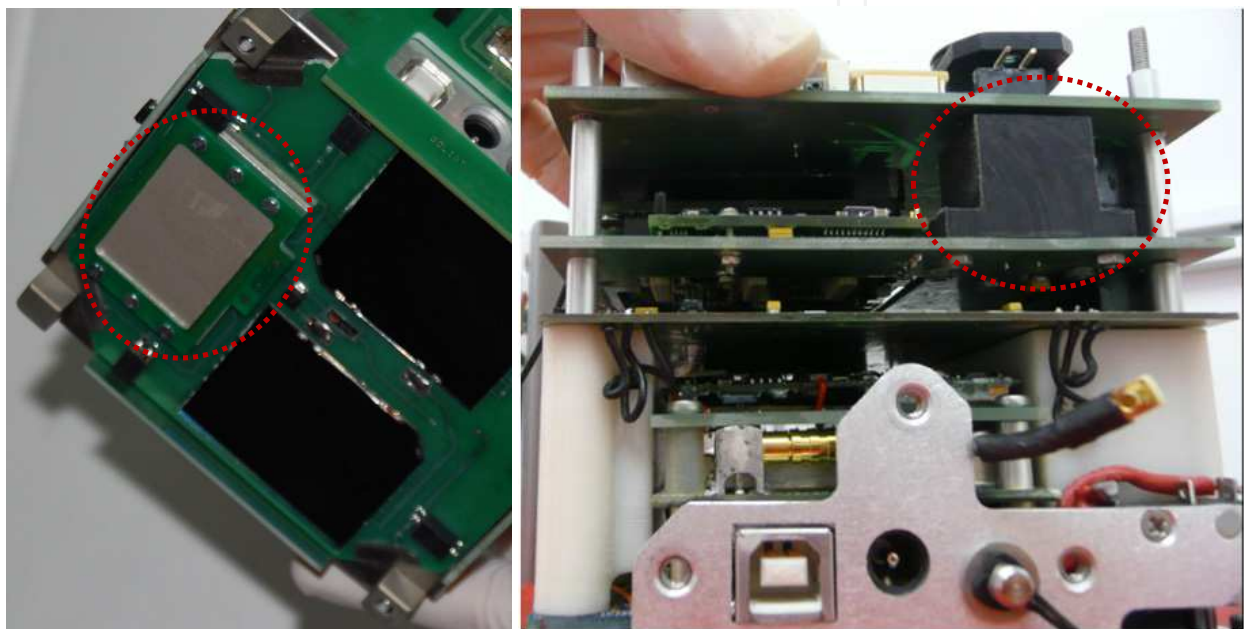
Fig. 5. Micro-meteoroid impact sensor (left) and radiation detector (right). Integrated on Goliat.

The third and the last of the experiments on board Goliat is a narrow angle camera (NAC). The sensor of the camera consists of a 2048 x 1536 matrix of pixels, the highest resolution fitted on a single unit CubeSat. The pixel size is 3.2 μm x 3.2 μm. For the electronics of the experiment a commercial solution with the sensor board stacked on top the processor board was used. The processor board features a Blackfin ADSP-BF561 dual core DSP running at 600 MHz. A μClinux operating system is installed on the microcontroller and software written in C/C++ can be compiled on the device. A dual interface, serial and SPI, is used to communicate with the other microcontrollers on the satellite and with the SD card. The power consumption for the two stacked boards is typically at 1 W and does not exceed 2.25 W according to the manufacturer.

For a typical nanosatellite orbit – circular at 700 km altitude – the expected equivalent area in a 3 mega pixel image is a 50 x 70 km region. The expected pixel resolution is tens of meters, enabling the identification of geographical features and even of large constructions at the ground. The elliptical orbit for the Vega launch will make possible testing the camera

at various altitudes in the 300 to 1450 km range. For the project a special lens mount was designed and built at PRO Optica in Bucharest. The optics had to be accommodated inside the satellite and compliance with the CubeSat standard was desired. The optics had to meet the restrictions of accommodating the other subsystems while maximizing the focal length. A 6⁰ field of view was achieved at a 57 mm focal length.

The main objective of the Goliat satellite is to demonstrate the potential of nanosatellites to execute complex experiments at low costs. An auxiliary objective was the development of a flight proven satellite platform that could be adapted for future application oriented space missions.
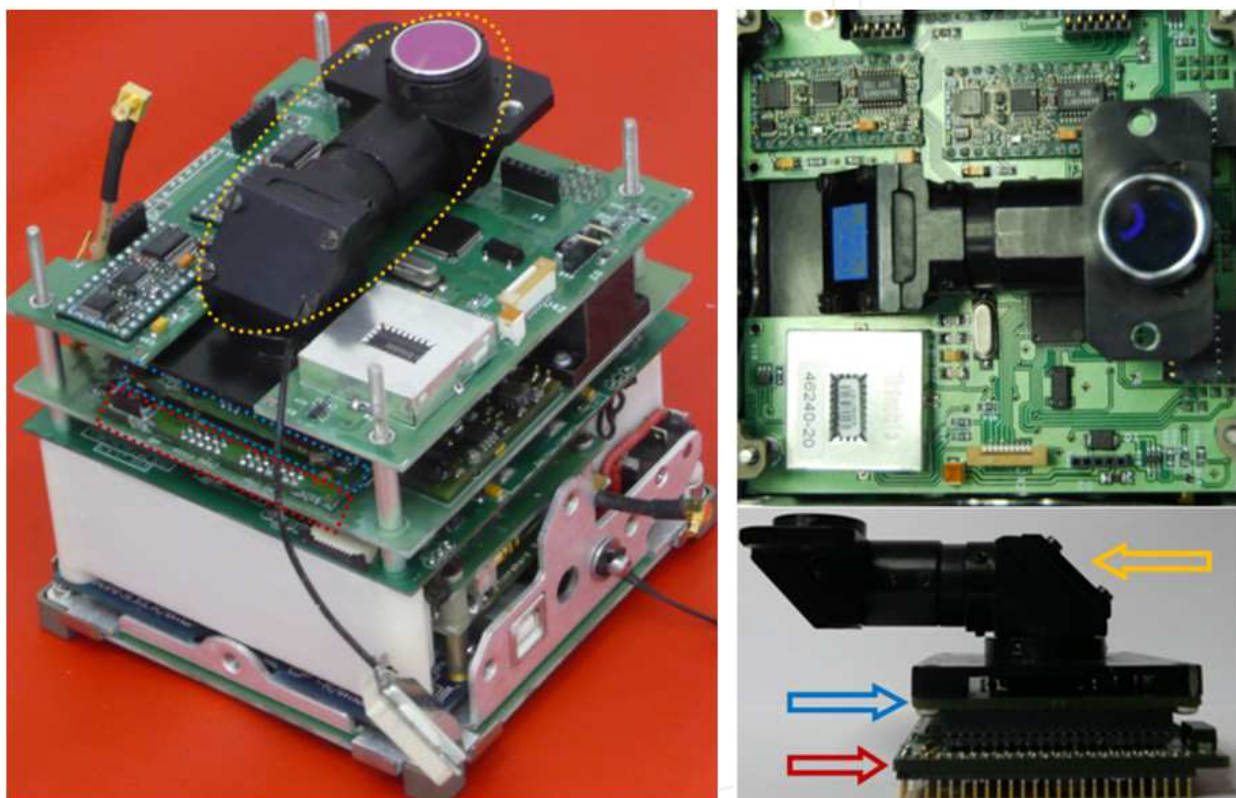
Fig. 6. The narrow angle camera on board Goliat: processor board (red), sensor board (blue), optics (yellow).

5. Conclusions

Nanosatellites are definitely the most rapid changing sector of the space industry in the last decade. Their development has taken many by surprise and their momentum is just starting to grow now that technologies essential for better exploiting their potential are becoming available. We are expecting their growth to continue due to the further reduction in costs and the decrease of the development cycle associated with the trend of standardizing the bus of the spacecraft.

At first missing, technologies like small scale AOCS systems, OBDH modules, and even low power, high data rate transceivers have rapidly evolved driven by their requirement in

building complex subsystems. It is now cheap to build more than one satellite and satellites are becoming smarter when connecting them in a network. Furthermore, the applications proposed for the new types of spacecrafts and missions promise to revolutionize space operations with the outside of the box thinking associated with doing things at a smaller scale.

Space is finally becoming accessible to projects with limited budgets, through nanosatellites, the new tools for near Earth explorations.

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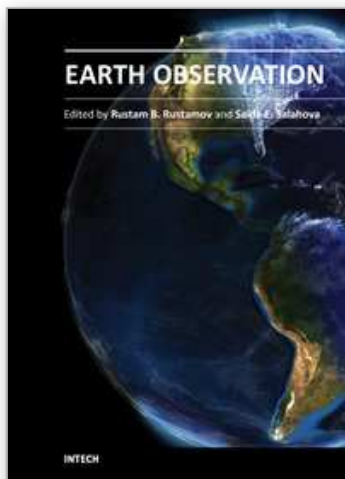
Earth Observation

Edited by Dr. Rustam Rustamov

Today, space technology is used as an excellent instrument for Earth observation applications. Data is collected using satellites and other available platforms for remote sensing. Remote sensing data collection detects a wide range of electromagnetic energy which is emitting, transmitting, or reflecting from the Earth's surface. Appropriate detection systems are needed to implement further data processing. Space technology has been found to be a successful application for studying climate change, as current and past data can be dynamically compared. This book presents different aspects of climate change and discusses space technology applications.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Marius Trusculescu, Mugurel Balan, Claudiu Dragasanu, Alexandru Pandele and Marius-Ioan Piso (2012). Nanosatellites: The Tool for Earth Observation and Near Earth Environment Monitoring, Earth Observation, Dr. Rustam Rustamov (Ed.), ISBN: 978-953-307-973-8, InTech, Available from: http://www.intechopen.com/books/earth-observation/nanosatellites-the-tool-for-earth-observation-and-near-earth-environment-monitoring

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